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Marketing Research Report No. 703

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Gamma Radiation
# of VEGETABLES
To Extend Market Life

Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE

PREFACE

The research reported here was conducted in cooperation with the U.S. Atomic Energy Commission under contract number AT(49–11)–2342. The mobile cobalt 60 irradiation unit was leased from Atomic Energy of Canada, Limited, and was located in Fresno, Calif., from June 17, 1963, to April 1, 1964.

M. J. Ceponis and F. M. Porter, U.S. Department of Agriculture Market Pathology Laboratory, Belle Mead, N.J., evaluated the shipping test with tomatoes, and J. N. Yeatman of the Horticultural Crops Laboratory at Beltsville, Md., conducted taste-panel tests with sweetpotatoes. A. E. Smith, Southwestern Radiological Health Laboratory, Las Vegas, Nev., evaluated samples of cantaloups for radioactive contamination and induced radiation.

Radiation and radiation sources intended for use in the production, processing and handling of food are defined as food additives by the Federal Food, Drug and Cosmetics Act, and food so treated is subject to its provisions. The Food and Drug Administration must promulgate regulations establishing the conditions under which such radiations may be safely used on specific foods before such products may be legally shipped for marketing. Thus far (May 17, 1965) regulations have been issued clearing radiation processing of bacon, wheat and wheat products, and white potatoes. FDA is considering a petition requesting a regulation for the irradiation of oranges. No petitions for irradiation of other fruits or vegetables have been submitted.

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SUMMARY

Eleven kinds of fresh vegetables were tested to evaluate the possible extension of their market life by irradiation. Radiation reduced postharvest growth of mushrooms without apparent impairment of quality. Sprouting of sweetpotatoes was inhibited by radiation, but susceptibility of the roots to decay was increased by relatively low doses. Decay of some lots of tomatoes was reduced, but radiation caused mottling and softening of the fruits. Decay of cucumbers, summer squash, and cantaloups was not consistently affected by radiation, but softening of these vegetables was increased by the treatments, and the fresh green appearance of cucumbers and scallop squash was impaired. Radiation caused softening, yellowing, and calyx discoloration of peppers, stem pitting and discoloration of globe artichokes, and severe spotting and discoloration of lettuce and endive, and accelerated quality loss in sweet corn.

GAMMA RADIATION OF VEGETABLES TO EXTEND MARKET LIFE

By William J. Bramlage *and* Werner J. Lipton,[1] *Market Quality Research Division, Agricultural Research Service*

BACKGROUND

Radiation pasteurization, the use of low doses of ionizing radiation to reduce microbial spoilage of foodstuffs, has received much attention in recent years. Although micro-organisms vary in susceptibility to radiation, complete sterilization of certain processed foods has been achieved through high-dose irradiation. Fresh fruits and vegetables cannot be treated with sterilizing doses; being living matter, they, as well as the micro-organisms involved, are susceptible to radiation injury. Nevertheless, relatively low doses of gamma radiation do retard the growth of some serious pathogens (*1*) [2] such as *Alternaria tenuis* and *Botrytis cinerea*. The degree of control of these pathogens by irradiation depends on the resistance by the host to radiation doses that are inhibitory to the micro-organisms.

Direct effects of radiation injury on the host sometimes are of benefit. Inhibition of the growing points, for example, slows the sprouting of potatoes (*8*) and onions (*3*). These effects are obtained from very low doses of radiation.

Many different kinds of vegetables have been irradiated during the last two decades, but much of this work has been with processed rather than with fresh material. Results of most of these tests have been reviewed previously (*6, 9, 10*).

The study reported here was undertaken in cooperation with the U.S. Atomic Energy Commission as part of a broad study of the feasibility of radiation pasteurization of foods, described by Shea (*7*). Our study was conducted to evaluate the extension of the market life of fresh fruits and vegetables by irradiation and to relate other factors, such as varietal differences and maturity, to radiation responses. This report includes only the results of irradiation of vegetable crops; results for fruit crops are presented in a separate report (*2*).

IRRADIATION FACILITY AND GENERAL METHODS

Vegetables were treated in a trailer-mounted irradiator containing a 40,000 curie source of cobalt 60. Produce to be irradiated was placed in aluminum buckets, which had internal dimensions of 15 by 7½ by 7½ inches. These buckets were conveyed into the irradiation chamber, where they revolved around the rod-type source on a "ferris wheel" mechanism. The chamber held eight buckets at one time, and the length of time a bucket remained in the chamber determined the total dose the produce received. Because the buckets entered and left the radiation positions one at a time, the radiation dose given to the contents of any one bucket was independent of the dose given any other bucket. The dose rate of about 5 kilorad (krad) per minute was constant, and the design of this irradiator provided a maximum dose variation of ±13 percent within each bucket. Although the irradiation chamber was equipped with a refrigerated air ventilation system, the air temperature in the irradiation chamber remained higher than the temperature of the produce. However, the maximum surface temperature rise of produce during irradiation was only about 5° F.

Eleven different kinds of vegetables were irradiated. Treatment was followed in most of the tests by storage at temperatures and for periods of time simulating those that occur during normal transit and marketing. In one test, tomatoes were shipped by rail to New York City and were examined in the U.S. Department of Agriculture Market Pathology Laboratory. In all tests, controls consisted of samples that had been passed through the irradiator with the cobalt source withdrawn from the irradiation chamber.

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[1] W. J. Bramlage is now with the Massachusetts Agricultural Experiment Station, Amherst. W. J. Lipton is at the Market Quality Research Division's Horticultural Crops Laboratory, 2021 S. Peach Avenue at Fresno, Calif.

[2] Italic numbers in parentheses refer to items in Literature Cited, p. 13.

Most of the data were statistically analyzed by an analysis of variance. The entire array of means for any analysis was separated by the Duncan multiple-range test, but only the more meaningful comparisons are given in the tables. In some cases an adequate estimate of error variance could not be obtained by an analysis of variance; hence, the data were analyzed by the chi-square contingency table method (*4*, pp. 38–72).

METHODS AND RESULTS FOR SPECIFIC VEGETABLES

Sweetpotatoes

Three varieties of sweetpotato (*Ipomoea batatas* L.) were tested: Yellow Jersey, Porto Rico, and No. 23. Replicate lots of Jersey and Porto Rico roots were obtained from two growers, but only one lot of No. 23 roots was tested. The roots were sorted to eliminate those misshapen or injured, and all sprouts were removed. The sweetpotatoes were then put in paper bags (8 roots per sample for No. 23, 10 for Jersey and Porto Rico) and recured for 7 days at about 72° F. and at a high relative humidity. Samples were irradiated with 0, 8.25, 16.5, 25, 200, or 300 krad and were stored at 59° or at 50° (in chilling injury range) for 3, 4.5, or 6 months (storage period); half of the samples were examined on removal from storage, and half after being held 14 days at 65° to 70° (holding period). The chilling temperature was used to determine whether or not radiation would reduce decay that is induced by chilling injury. Sprouting of the roots was rated according to the length of the longest sprout, as follows: 1=5 millimeters (mm.) or less; 2=6 to 10 mm.; 3=11 to 20 mm.; 4=21 to 50 mm.; 5=more than 50 mm. Following storage at 59° for 4.5 months, samples of Yellow Jersey and Porto Rico roots that had been irradiated with 0, 8.25, or 16.5 krad were evaluated for flavor differences at the Horticultural Crops Laboratory, Beltsville, Md., by means of paired comparisons. Three samples, unknown to the judges, were compared with a nonirradiated reference sample. Since one of the unknowns was also not irradiated, it also could be judged to be different from the reference sample.

Sweetpotatoes were severely injured by exposure to 200 or 300 krad. Following storage for 3 months, all roots exposed to these doses were decayed; figures are not tabulated for these treatments. The effects of the lower radiation doses on decay were influenced by both variety and storage temperature (tables 1 and 18). Chilling and radiation stimulated decay on Yellow Jersey and Porto Rico, and the chilling effect was worse on irradiated than on unirradiated roots. Nearly all roots of variety No. 23 decayed regardless of treatment. Twenty-five krad increased decay regardless of storage temperature, but 8.25 and 16.5 krad increased decay only when the roots were stored at the chilling temperature. Fusarium surface rot, as described by Ramsey and others (*5*), was the primary type of decay, but several other types developed subsequently as secondary invaders. Radiation had a similar effect on the roots from both growers.

Weight loss from the stored roots was increased by radiation, especially during storage at chilling temperature (table 1). The increased loss of weight was due primarily to the increased decay following irradiation. Weight loss during storage at 59° F. was not significantly increased by 8.25 or 16.5 krad. Radiation accelerated weight loss during each one of the three storage periods, but the effect was most pronounced after 6 months (table 2).

Sprouting of the stored roots was variable, occurring least on No. 23 and most on Yellow Jersey, and as expected, much less at 50° F. than at 59° (table 1). Radiation reduced the percent of roots that sprouted, but the dose required for a significant reduction depended on the variety and storage temperature. Radiation also reduced the length of the sprouts that developed, with 8.25 krad effectively inhibiting growth of the sprouts that did occur, regardless of variety or storage temperature (table 3). Thus, 8.25 krad did not prevent sprouting of sweetpotatoes but did reduce the number of sprouts and did inhibit their growth (fig. 1).

The flavor of Yellow Jersey and Porto Rico sweetpotatoes was not affected by treatment with 8.25 krad, but the flavor of Porto Rico roots was altered by 16.5 krad (table 4). Preferences were not evaluated in these tests.

Mushrooms

In the United States, mushrooms (*Agaricus campestris* L. ex Fr.) are preferred in an immature stage with the cap unopened. Following harvest, however, mushrooms continue to grow—the stalk elongates, the cap opens, and the gills darken. Since these expressions of growth rapidly reduce their value, a white strain of mushrooms was irradiated in an attempt to suppress these postharvest changes.

The mushrooms were packed in pint cups overwrapped with a moisture-permeable film. In test

1, duplicate samples were irradiated with 0, 100, 200, 300, or 400 krad and were held for 2 or 4 days at 38° F. plus 2 or 4 days at 65° before examination. The mushrooms were rated for cap opening on the scale: 1=closed; 5=partially open; 9=completely open.

In test 2, the samples were exposed to 0, 6.3, 12.5, 25, 50, or 100 krad and were held for 6 days at 32° plus 2 or 4 days at 70° before examination. In this test, opening was rated on the scale: 1=tightly closed; 3=puffy but closed; 5=slightly open; 7=moderately open; 9=completely open.

TABLE 1.—*Decay, weight loss, and sprouting of sweetpotatoes as a function of radiation dose. variety, and storage temperature* [1]

Criteria, variety, and storage temperature	0 krad	8. 25 krad	16. 5 krad	25 krad
ROOTS WITH DECAY				
Porto Rico:	*Percent*	*Percent*	*Percent*	*Percent*
50° F	52 a	55 ab	75 bc	94 c
59° F	12 a	23 a	19 a	43 b
Yellow Jersey:				
50° F	60 a	93 b	99 b	100 b
59° F	3 a	21 a	24 a	84 b
No. 23:				
50° F	100 a	98 a	100 a	100 a
59° F	73 a	65 a	72 a	92 a
WEIGHT LOSS				
Porto Rico:				
50° F	10 a	13 a	14 a	19 b
59° F	9 a	12 ab	11 ab	15 b
Yellow Jersey:				
50° F	10 a	15 b	17 b	22 c
59° F	10 a	12 a	13 a	15 a
No. 23:				
50° F	11 a	10 a	13 a	21 b
59° F	9 a	10 a	10 a	15 b
ROOTS WITH SPROUTS				
Porto Rico:				
50° F	27 a	18 ab	17 b	0 b
59° F	48 a	40 a	25 ab	12 b
Yellow Jersey:				
50° F	23 a	10 a	5 a	4 a
59° F	93 a	51 b	33 bc	11 c
No 23:				
50° F	10 a	2 a	0 a	0 a
59° F	27 a	10 b	2 b	0 b

[1] Any 2 means on a given line not followed by the same letter are significantly different from each other at the 1-percent level.

The data are the means of the examinations after the 3 storage periods (3, 4½, and 6 months) and after 14 additional days at 65° to 70° F. combined.

The data for Porto Rico and Yellow Jersey varieties were analyzed together. Those for No. 23 were analyzed separately because this variety was obtained from only one source.

TABLE 2.—*Weight loss of sweetpotatoes as a function of radiation dose and duration of storage* [1]

Storage period at 50° or 59° F.	0 krad	8.25 krad	16.5 krad	25 krad
	Percent	*Percent*	*Percent*	*Percent*
3 months	7. 4 a	8. 8 ab	8. 9 ab	11. 4 b
4.5 months	10. 4 a	12. 2 a	13. 3 a	16. 7 b
6 months	12. 3 a	17. 1 b	18. 8 b	25. 1 c

[1] Any 2 means on a given line not followed by the same letter are significantly different from each other at the 1-percent level.

The data are the means of the examinations after storage and after 14 additional days at 65° to 70° F., and for Porto Rico and Yellow Jersey varieties combined.

TABLE 3.—*Sprouting of sweetpotatoes during storage as a function of radiation dose, variety, and storage temperature* [1]

Variety and storage temperature	0 krad	8.25 krad	16.5 krad	25 krad
Porto Rico:	*Rating*	*Rating*	*Rating*	*Rating*
50° F	1. 2	1. 1	1. 0	—
59° F	1. 4	1. 2	1. 0	1. 1
Yellow Jersey:				
50° F	1. 4	1. 0	1. 0	1. 0
59° F	2. 9	1. 1	1. 2	1. 0
No. 23:				
50° F	1. 4	1. 0	—	—
59° F	1. 1	1. 0	1. 0	—

[1] Rating scale (length of longest sprout): 1=5 mm. or less; 2=6 to 10 mm.; 3=11 to 20 mm.; 4=21 to 50 mm.; 5=more than 50 mm.

The data could not be statistically analyzed due to the many missing values where no sprouts developed in a sample. The data are the averages of the ratings after the 3 storage periods (3, 4½, or 6 months) and after holding 14 additional days at 65° to 70° F. combined.

Dashes indicate no sprouting.

TABLE 4.—*Taste test of baked sweetpotatoes held 4½ months at 59° F. as a function of radiation dose and variety* [1]

Variety	Number of times out of 20 samplings that roots were judged to taste different from unirradiated reference samples		
	0 krad	8.25 krad	16.5 krad
Porto Rico	7 a	11 a	14 b
Yellow Jersey	10 a	9 a	12 a

[1] Any 2 means on a given line not followed by the same letter are significantly different at the 5-percent level by chi-square analysis.

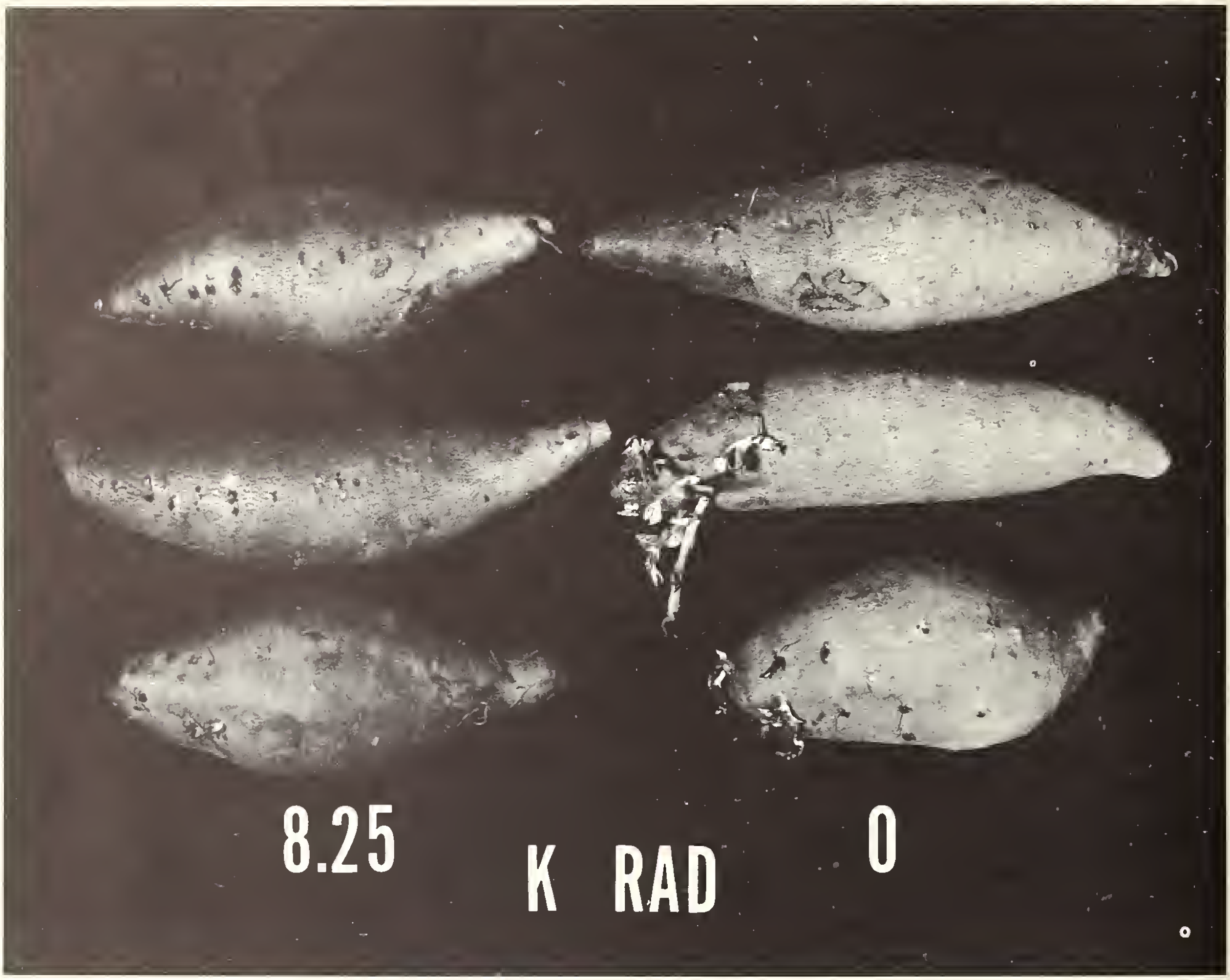

FIGURE 1.—Inhibition of sprouting of Yellow Jersey sweetpotatoes by irradiation. Roots held 3 months at 59° F. plus 14 days at 65° to 70°. Note small sprout on lower irradiated root—this was most severely sprouted root treated with 8.25 krad. Range of sprouting is shown for 0 krad.

In addition, the length of the mushrooms from the top of the cap to the cut end of the stalk was measured before irradiation and after the holding periods.

In test 3, radiation doses of 0, 50, 75, and 100 krad were applied, and the samples were stored for 3 days at 41° plus 3, 5, or 7 days at 50°. Half of the samples were placed in vented polyethylene bags to reduce moisture loss during storage at 41°. Cap opening in test 3 was rated on the scale used in test 2. The increase in length of the mushrooms during 3 days at 41° plus 6 days at 50° was determined.

Radiation reduced postharvest growth of mushrooms. All levels of dosage, from 6.3 to 400 krad, inhibited opening of the caps, and all doses were equally effective (table 5). Because caps also opened during storage at low temperatures, the effect of the treatments was apparent at all examinations. In the first test, irradiated mushrooms seemed to elongate less than the controls, and the measurements made in the two later tests substantiated this observation (table 5). In these tests, 100 krad significantly inhibited elongation, which occurred almost exclusively during holding at 70° or 50° F., respectively. Radiation inhibited expansion and darkening of the gills, and thus irradiated mushrooms were more attractive than unirradiated mushrooms when sliced. Those irradiated were slightly grayer externally than the controls, but there was less external browning following irradiation.

During the first two tests, the unirradiated samples became moldy. In test 1, all radiation doses prevented mold growth; in test 2, 6.3 and 12.5 krad did not control mold, but no mold developed following 25 to 100 krad. In test 3, mold did not develop on any of the mushrooms.

All of the samples in test 2 showed symptoms of dehydration by the last examination. In test 3, in which some samples were packed in polyethylene, none of the samples became dehydrated, whether packaged in polyethylene or not. Apparently, holding at 50° instead of at 70° F. substantially reduced moisture loss.

TABLE 5.—*Opening of the caps and elongation of the stalks of mushrooms as a function of radiation dose* [1]

Test No. and radiation dose	Opening of caps [2]	Increase in length of stalks [3]
TEST 1 [4]	*Rating*	*Percent*
0 krad	5.4 a	—
100 krad	2.6 b	—
200 krad	2.6 b	—
300 krad	2.2 b	—
400 krad	2.2 b	—
TEST 2 [4]		
0 krad	5.3 a	13.9 a
6.3 krad	2.1 b	13.8 a
12.5 krad	2.0 b	10.0 ab
25 krad	1.7 b	10.1 ab
50 krad	1.3 b	10.4 ab
100 krad	1.3 b	6.5 b
TEST 3 [4]		
0 krad	5.8 a	26.2 a
50 krad	1.2 b	19.8 ab
75 krad	2.6 b	16.5 ab
100 krad	1.8 b	13.3 b

[1] Any 2 means in a column of a given test not followed by the same letter are significantly different from each other at the 1-percent level. The data are means for all storage periods.

[2] Rating scales: Test 1: 1=closed; 5=partially open; 9=completely open. Tests 2 and 3: 1=tightly closed; 3=puffy but closed; 5=slightly open; 7=moderately open; 9=completely open.

[3] Length of mushrooms from top of cap to cut end of stalk was measured before irradiation and after all holding periods in test 2, and after 6 days' holding in test 3.

[4] Test 1: Samples stored 2 or 4 days at 38° F. plus 2 or 4 days at 65° before examination. Test 2: Samples stored 6 days at 32° plus 2 or 4 days at 70° before examination. Test 3: Samples stored 3 days at 41° plus 3, 5, or 7 days at 50°; half the samples were placed in vented polyethylene bags.

Radiation extended the market life of mushrooms by maintaining them in a fresh-appearing condition. Although 100 krad was necessary to significantly inhibit stalk elongation, mushrooms exposed to 50 krad were just as attractive as those exposed to 100 krad. Doses of 25 krad or less were not as effective as 50 krad in maintaining a fresh appearance.

Tomatoes

Tomatoes (*Lycopersicon esculentum* Mill.) were irradiated in four tests. The first three tests included mature green (no pink), "breaker" (trace of pink at blossom end), light pink, and pink fruits. The variety Early-Pack 7 was used in tests 1 and 2, and the variety Pearson in test 3.

In test 1, samples of 10 fruits were packed in paper bags, irradiated with 0, 125, 250, or 500 krad, and held at 37° F. (a chilling temperature) for 0, 4, or 8 days before ripening at 70°; separate samples were examined after 3 different periods of ripening, the periods depending on the rates of ripening.

Test 2 was the same as test 1, except that the tomatoes were held at 37° for 0, 4, or 8 days before, rather than after, irradiation.

In test 3, fruits commercially packed in plastic trays (four fruits per tray and overwrapped with shrink film) were irradiated with 0, 125, 250, or 375 krad; they were stored at 59° for 8 days and then at 70° for two or four different lengths of time. A sample consisted of five trays of tomatoes, each being treated statistically as a subsample.

At each examination the fruits were evaluated for decay, firmness, and color. Firmness was determined subjectively using a rating scale in which 1=unacceptably soft, 3=noticeably softened, and 5=firm. Color was evaluated on a scale in which 1=5 percent or less of surface pink or light red, 2=6 to 50 percent of surface pink or light red, 3=51 to 90 percent of surface pink or light red, 4=91 to 100 percent of surface pink or light red, 5=100 percent of surface fully red. Mottling of the color was rated on a scale in which 1=none, 2=trace, 3=slight, 4=moderate, and 5=severe.

Decay developed on a very few of the nonchilled Early-Pack 7 tomatoes, but developed on many of the chilled ones (table 6). Irradiated fruits that were subsequently chilled for 8 days (test 1) developed more decay than the nonirradiated ones, indicating that radiation increased susceptibility to chilling injury. However, radiation reduced decay on Early-Pack 7 tomatoes that were chilled 8 days before irradiation (test 2), but the reduction was significant only with 250 or 500 krad. Nonchilled Pearson tomatoes irradiated with 375 krad had significantly less decay than nonirradiated fruit or fruit irradiated with 125 krad.

Tomatoes were significantly softened by radiation (table 7). This softening persisted throughout the ripening periods of Early-Pack 7, but was apparent only at the early examinations of Pearson tomatoes. The initially riper fruits softened more than those less ripe.

TABLE 6.—*Decay of tomatoes during ripening as a function of radiation dose, variety, and chilling exposure* [1]

Variety, duration of chilling, or storage before ripening	0 krad	125 krad	250 krad	375 krad	500 krad
Early-Pack 7 (in paper bags):					
Test 1, chilled at 37° F. after irradiation:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
No chilling	0 a	0 a	0 a	—	0 a
Chilled 4 days	6 a	19 a	10 a	—	17 a
Chilled 8 days	30 a	66 c	58 bc	—	44 ab
Test 2, chilled at 37° before irradiation:					
No chilling	8 a	3 a	0 a	—	0 a
Chilled 4 days	7 a	12 a	7 a	—	2 a
Chilled 8 days	37 a	35 a	13 b	—	5 b
Pearson (in plastic trays overwrapped with shrink film):					
Test 3, stored 8 days at 59° after irradiation	18 a	17 a	10 ab	2 b	—

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[1] Any 2 means on a given line not followed by the same letter are significantly different from each other at the 1-percent level.
Data are means for all ripening periods at 70° F. and for all initial degrees of ripeness.

TABLE 7.—*Firmness of tomatoes as a function of radiation dose, variety, initial ripeness, and ripening time* [1]

Variety, initial ripeness, and days ripened at 70° F.	0 krad	125 krad	250 krad	375 krad	500 krad
Early-Pack 7 (in paper bags): [2]					
Test 1:	*Rating*	*Rating*	*Rating*	*Rating*	*Rating*
Mature green, ripened 9–16 days	2.9 a	2.7 a	2.7 a	—	2.5 a
Breaker, ripened 4–11 days	3.6 a	3.2 ab	2.9 b	—	2.4 b
Pink, ripened 4–8 days	3.5 a	3.1 ab	2.8 bc	—	2.3 c
Test 2:					
Mature green, ripened 7–15 days	3.6 a	3.4 a	3.3 a	3.2 a	—
Breaker, ripened 4–11 days	3.2 a	2.9 ab	2.5 b	2.6 b	—
Pearson (in plastic trays overwrapped with shrink film):					
Test 3 (held 8 days at 59° after irradiation):					
Breaker:					
Ripened 5 days	4.2 a	3.7 ab	3.3 b	3.5 ab	—
Ripened 9 days	3.1 a	3.1 a	3.0 a	2.8 a	—
Ripened 15 days	2.9 a	2.7 a	2.5 a	3.2 a	—
Ripened 19 days	2.6 a	2.6 a	2.4 a	2.6 a	—
Light pink:					
No ripening at 70° [3]	4.5 a	3.6 b	3.4 b	3.3 b	—
No ripening at 70°	4.2 a	3.9 ab	3.5 ab	3.0 b	—
Ripened 5 days	3.5 a	3.3 a	3.2 a	3.0 a	—
Ripened 9 days	2.8 a	2.4 a	2.7 a	2.5 a	—

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[1] Any 2 means on a given line not followed by the same letter are significantly different from each other at the 1-percent level.
Rating scale: 1=unacceptably soft; 3=noticeably softened; 5=firm.
[2] The data are means for chilling periods of 0, 4, or 8 days at 37° F. combined.
Test 1, chilled after irradiation; test 2, chilled before irradiation.
[3] Held 6 days at 59° instead of 8 days.

Radiation had a marked effect on coloring of tomatoes (table 8). Doses of 125 and 250 krad inhibited coloring of mature green Early-Pack 7 tomatoes in test 2, though not in test 1, and 375 krad inhibited coloring of Pearson tomatoes, but these fruits eventually attained full red color. However, 500 krad prevented the fruits from becoming fully colored, even when they were held beyond the listed ripening periods. Initial degree of ripeness of the fruits influenced the effect of radiation on coloring; mature-green fruits were most severely retarded; and pink tomatoes were least affected.

Besides influencing the rate of coloring, radiation affected the uniformity of coloring. Irradiated tomatoes usually retained areas of green or yellow in the overall pink or red fields, causing a mottled appearance. Mottling was worse on Early-Pack 7 than on Pearson tomatoes (table 9); only the less ripe Pearson fruits were affected. Initial ripeness did not influence mottling on Early-Pack 7 tomatoes. Mottling sometimes appeared to be worse following the low radiation doses than following the high doses (table 9). This was not due to less injury at high doses, but rather to less red pigmentation; the injury simply was more noticeable on redder fruits.

Upon completion of the three tests, which simulated shipping conditions, a fourth test was conducted in which irradiated tomatoes were shipped via rail from Sanger, Calif., to New York City. Fruits from the same lot were held at Fresno to permit evaluation of differences attributable to transit. Breaker and light pink Homestead tomatoes, commercially packed in plastic trays and overwrapped with shrink film, were irradiated with 0, 175, and 250 krad. The fruit held in Fresno was examined after 8 days at 50° F. plus 4, 6, 8, or 10 days at 65° F. The fruit shipped to New York was exposed to unintentional chilling temperatures of 35° to 45° during the 8 days in transit. These samples were examined after 4, 6, 8, or 11 days at 70° F.

Results of this test are summarized in table 10. Decay, primarily Alternaria rot, was reduced by 250 krad in the samples shipped to New York, but not in those held in Fresno. Overall coloring was only slightly affected by radiation, but radiation-induced mottling and softening were reported from New York. The effects of irradiation were not modified by either initial ripeness or by ripening time (table 19).

TABLE 8.—*Coloring of tomatoes as a function of radiation dose, variety, initial ripeness, and ripening time* [1]

Variety, initial ripeness, and days ripened at 70° F.	0 krad	125 krad	250 krad	375 krad	500 krad
Early-Pack 7 (in paper bags): [2]					
Test 1:					
Mature green:	*Rating*	*Rating*	*Rating*	*Rating*	*Rating*
Ripened 9–11 days	2. 5 a	2. 7 a	2. 3 a	—	1. 2 b
Ripened 12–14 days	4. 3 a	4. 0 a	3. 9 a	—	2. 1 b
Ripened 15–16 days	4. 9 a	4. 6 a	3. 9 a	—	2. 7 b
Breaker:					
Ripened 4–6 days	4. 5 a	4. 0 a	3. 9 a	—	2. 5 b
Ripened 6–8 days	4. 8 a	4. 2 a	4. 0 a	—	2. 7 b
Ripened 6–11 days	4. 9 a	4. 9 a	4. 2 a	—	2. 9 b
Pink:					
Ripened 4–5 days	4. 3 a	4. 4 a	4. 5 a	—	3. 6 a
Ripened 5–7 days	4. 8 a	4. 8 a	4. 7 a	—	4. 1 a
Ripened 5–8 days	4. 9 a	4. 8 a	4. 8 a	—	3. 9 a
Test 2:					
Mature green:					
Ripened 7–8 days	3. 4 a	2. 3 b	2. 2 bc	—	1. 5 c
Ripened 11 days	4. 5 a	4. 1 a	3. 9 a	—	2. 6 b
Ripened 14–15 days	4. 6 a	4. 9 a	4. 7 a	—	3. 0 b
Breaker:					
Ripened 4 days	3. 9 a	3. 6 a	3. 6 a	—	3. 3 a
Ripened 6–7 days	4. 9 a	4. 8 a	4. 7 a	—	3. 3 b
Ripened 9–11 days	5. 0 a	4. 9 a	4. 9 a	—	4. 1 a
Pearson (in plastic trays overwrapped with shrink film):					
Test 3 (held 8 days at 59° after irradiation):					
Breaker:					
Ripened 5 days	4. 9 a	4. 6 a	4. 7 a	3. 9 b	—
Ripened 9 days	5. 0 a	5. 0 a	4. 9 a	4. 3 b	—
Ripened 15 days	5. 0 a	5. 0 a	4. 9 a	4. 8 a	—
Ripened 19 days	5. 0 a	5. 0 a	5. 0 a	5. 0 a	—
Light pink:					
No ripening at 70° [3]	4. 7 a	4. 4 ab	4. 3 ab	4. 0 b	—
No ripening at 70°	4. 8 ab	5. 0 a	4. 8 ab	4. 4 b	—
Ripened 5 days	4. 0 a	5. 0 a	5. 0 a	5. 0 a	—
Ripened 9 days	5. 0 a	5. 0 a	5. 0 a	5. 0 a	—

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[1] Any 2 means on a given line not followed by the same letter are significantly different from each other at the 1-percent level.

Rating scale: 1=5 percent or less of surface pink or light red; 2=6 to 50 percent pink or light red; 3=51 to 90 percent pink or light red; 4=91 to 100 percent pink or light red; 5=100 percent of surface fully red.

[2] The data are the means for chilling periods of 0, 4, or 8 days at 37° F. combined.

Test 1, chilled after irradiation; test 2, chilled before irradiation.

[3] Held 6 days at 59° F., instead of 8 days.

TABLE 9.—*Mottling of tomatoes during ripening as a function of radiation dose, variety, chilling exposure, and initial ripeness* [1]

Variety and test conditions	0 krad	125 krad	250 krad	375 krad	500 krad
Early-Pack 7 (in paper bags):[2]					
Test 1, chilled at 37° F. after irradiation:	*Rating*	*Rating*	*Rating*	*Rating*	*Rating*
No chilling	1. 1 a	1. 5 ab	2. 0 ab	—	1. 8 b
Chilled 4 days	1. 1 a	1. 2 a	1. 7 b	—	1. 3 ab
Chilled 8 days	1. 1 a	1. 5 ab	1. 8 b	—	1. 2 a
Test 2, chilled at 37° before irradiation:					
No chilling	1. 0 a	1. 4 ab	1. 8 b	—	2. 4 c
Chilled 4 days	1. 0 a	1. 2 ab	1. 7 b	—	1. 7 b
Chilled 8 days	1. 0 a	1. 2 a	1. 5 a	—	1. 2 a
Pearson (in plastic trays overwrapped with shrink film):					
Test 3, stored 6 or 8 days at 59° after irradiation:					
Breaker [3]	1. 0 a	1. 0 a	1. 4 b	2. 1 c	—
Light pink [3]	1. 0 a	1. 0 a	1. 1 a	1. 2 a	—

[1] Any 2 means on a given line not followed by the same letter are significantly different from each other at the 1-percent level.
The data are means for all ripening periods at 70° F.
Rating scale: 1=none; 2=trace; 3=moderate; 5=severe.

[2] Initial ripeness did not modify the effect of irradiation on mottling of Early-Pack 7 tomatoes.

[3] Initial ripeness. The data are means for all storage and ripening periods.

TABLE 10.—*Decay, coloring, mottling, and softening of Homestead tomatoes after simulated and actual shipping as a function of radiation dose* [1]

Quality criteria	0 krad	175 krad	250 krad
Held in Fresno:[2]			
Fruits with decay percent	30. 0 a	22. 0 a	22. 0 a
Coloring rating [3]	5. 0 a	4. 9 ab	4. 8 b
Mottling do.[4]	1. 1 a	1. 2 a	1. 2 a
Softening do.[5]	2. 9 a	2. 8 a	2. 5 a
Shipped by rail to New York City:[6]			
Fruits with decay percent	43. 0 a	52. 0 a	19. 0 b
Coloring rating [3]	4. 9 a	4. 8 a	4. 8 a
Mottling do.[4]	1. 2 a	1. 6 b	1. 7 b
Softening do.[5]	3. 6 a	2. 9 b	3. 2 ab

[1] Any 2 means in a given line not followed by the same letter are significantly different from each other at the 1-percent level.

[2] The data are means for ripening 4, 6, 8, or 10 days at 65° F. subsequent to storage at 50° F. for 8 days.

[3] Rating scale: 1=5 percent or less of surface pink or light red; 2=6 to 50 percent pink or light red; 3=51 to 90 percent pink or light red; 4=91 to 100 percent pink or light red; 5=100 percent of surface fully red.

[4] Rating scale: 1=none; 3=moderate; 5=severe.

[5] Rating scale: 1=unacceptably soft; 3=noticeably softened; 5=firm.

[6] The data are means for ripening at 70° for 4, 6, 8, or 11 days subsequent to 8 days in transit, with unintentional chilling en route.

Irradiation of tomatoes at the breaker stage, or riper, may be feasible under some circumstances, but only if the deleterious effects, such as softening, are of less importance than a possible decay reduction.

Cucumbers

Ten-fruit samples of an unknown variety of cucumber (*Cucumis sativus* L.) were irradiated with 0, 75, 150, or 300 krad and were stored at 37° F. (chilling temperature) or 59°. Separate samples were examined after 7 days in storage and also after 3 additional days at 59°. In a second test, 10-fruit samples of Palomar cucumbers were irradiated with 0, 100, or 200 krad and were held at 70° for 24 hours before cold storage. Samples were examined after 8 days at 37° or 50°, and after 3 days at 59°. Yellowing, softening, and shriveling were evaluated on the following scale: 1=none; 2=trace; 3=slight; 4=moderate; and 5=severe.

In the first test, molds, which developed on the stem scars of the cucumbers, were greatly reduced by 300 krad (table 11). In the second test, the rots which developed on the cucumbers were not significantly affected by the doses used. Radiation increased yellowing in the second test but not in the first one. Radiation stimulated softening in both tests. The effects of radiation on decay, yellowing, and softening were not influenced by any other variable (table 20). However, a temperature-dependent effect on shriveling was noted in test 1: radiation reduced shriveling of cucumbers at 59°, but not at 37°. Weight loss was unaffected by radiation (data for test 2 only).

In test 1, numerous small, wartlike, tan areas developed on the surface of the cucumbers stored at 59° F., but not on those stored at 37°. The

TABLE 11.—*Decay, weight loss, yellowing, softening, and shriveling of cucumbers as a function of radiation dose and storage temperature* [1]

Test No. and quality criteria	0 krad	75 krad	100 krad	150 krad	200 krad	300 krad
TEST 1						
Fruits with stem-scar mold [2] percent	80. 0 a	80. 0 a	—	40. 0 ab	—	3. 0 b
Yellowing [2] rating [3]	2. 5 a	2. 7 a	—	2. 5 a	—	2. 7 a
Softening [2] do. [3]	2. 9 a	3. 1 ab	—	3. 7 bc	—	4. 4 c
Shriveling: [4]						
Storage at 37° (chilling) do. [3]	1. 3 a	1. 7 a	—	1. 5 a	—	2. 1 a
Storage at 59° (nonchilling) do. [3]	2. 4 a	1. 9 ab	—	1. 1 b	—	1. 0 b
TEST 2 [5]						
Fruits with decay percent	28. 0 a	—	13. 0 a	—	19. 0 a	—
Weight loss do.	1. 8 a	—	1. 8 a	—	1. 8 a	—
Yellowing rating [3]	2. 0 a	—	2. 1 a	—	2. 4 b	—
Softening do. [3]	1. 8 a	—	2. 3 b	—	2. 6 b	—

[1] Any 2 means on a given line not followed by the same letter are significantly different from each other at the 1-percent level.

[2] The data are the means of examinations after 7 days at 37° or 59° F., and after 3 additional days at 59° combined.

[3] Rating scale: 1=none; 2=trace; 3=slight; 4=moderate; 5=severe.

[4] The data are the means of examinations after chilling storage or nonchilling storage plus 3 additional days at 59°.

[5] The data are the means of examinations after 8 days at 37° or 50° F., and after 3 additional days at 59° combined. Samples were held at 70° for 24 hours before storage.

severity of the spotting, rated on the scale described above, was as follows:

Radiation dose (krad)	0	75	150	300
Spotting (rating)	3. 4	2. 5	1. 8	1. 0

Doses of 75 and 150 krad reduced the spotting, and 200 krad prevented it. This disorder could not be identified, and it did not occur on any fruits in the second test.

Summer Squash

Three types of summer squash (*Cucurbita pepo* L.) (white bush scallop, cultivar Benning Green Tint; yellow crookneck, cultivar Early Bush; and zucchini, cultivar Cozzini) were irradiated. Twenty-fruit samples, placed in paper bags, were treated with 0, 100, 200, or 300 krad, and stored at 37° F. (chilling temperature) or 55°. Separate samples were examined after 6 days in storage and after 2 more days at 55°. Weight loss and decay were determined, and softening was rated on the following scale: 1=none; 2=trace; 3=slight; 4=moderate; and 5=severe.

Radiation affected decay and softening, but not weight loss of squash. The responses to radiation were independent of variety, chilling, and holding time (table 21). Decay varied among the samples, but was reduced appreciably following 300 krad (table 12). Radiation increased softening of the squash, but the extent of softening was not considered objectionable. A slight bleaching of the green surface of irradiated scallop squash was observed at the second examination. Such fruits looked older than the controls.

TABLE 12.—*Decay and softening of summer squash as a function of radiation dose* [1]

Quality criteria	0 krad	100 krad	200 krad	300 krad
Fruits with decay percent	28 ab	38 a	27 ab	15 b
Softening rating [2]	1.7 a	2.0 a	2.2 bc	2.4 c

[1] Any 2 means on a given line not followed by the same letter are significantly different from each other at the 1-percent level.

The data are the means for the 3 types of squash and for examinations after 6 days at 37° or 55° F. and after 2 additional days at 55° combined.

[2] Rating scale: 1=none; 2=trace; 3=slight; 4=moderate; 5=severe.

Cantaloups

Cantaloups (*Cucumis melo* L., var. *reticulatus* Naud.) of the cultivar Powdery Mildew Resistant No. 45 were irradiated. In test 1, seven-melon samples of "Western choice" (firm, ready to eat, mostly yellow ground color) and "Eastern choice" (hard, ready to eat, half yellow-half green ground color) were irradiated with 0, 45, 125, and 375 krad, and stored at 37° F. They were examined after 7 or 10 days and again after 3 days at 59°.

In test 2, 10-melon samples of "hard ripe" (too hard for eating, generally green ground color) and Eastern choice melons were irradiated with 0, 125, 250, 375, or 500 krad, and stored at 37°. They were examined after 8 days and again after 4 or 7 days at 59°. In both tests, the same melons were examined after each period at 59°. Criteria evaluated were percentage of fruits with stem-scar mold or decay, ground color (scale: 1=25 percent or less of surface green; 2=26 to 50 percent green; 3=51 to 75 percent green; 4=76 to 100 percent green), and firmness (scale: 1=unacceptably soft; 3=optimum softness for eating; 5=hard).

Radiation influenced stem-scar mold, decay, and firmness of cantaloups, but did not greatly affect ground color (table 22). In test 1, 375 krad reduced stem-scar mold on the melons (table 13), but this response did not occur in test 2. Doses of 250 to 500 krad used in test 2 greatly increased general decay of the melons. Radiation softened the melons, but only slightly. Initial ripeness did not appreciably influence the responses of cantaloups to radiation (table 22).

Bell Peppers

Ten-fruit samples of Pepper Bowl peppers (*Capsicum annuum* L.) were irradiated with 0, 125, 250, 375, or 500 krad and stored at 37° F. (chilling temperature) or 50°. Separate samples were examined after 7, 12, or 15 days and after 3 or 4 additional days at 59°. Criteria evaluated were decay, firmness (scale: 1=unacceptably soft; 3=noticeably softened; 5=firm), color (1=dark green; 3=yellow-green; 5=yellow), and calyx discoloration (1=none; 2=trace; 3=slight; 4=moderate; 5=severe).

Radiation influenced firmness, coloring, and calyx discoloration, but not decay, which was slight in all samples (tables 14 and 23). Peppers exposed to 500 krad softened more rapidly than the controls. All doses of radiation stimulated yellowing of the fruits, but this stimulation was much more pronounced on peppers stored at 50° F. than on those stored at 37°. Calyx discoloration appeared as a browning and drying of the tissues; only the 500 krad dose caused discoloration on some unchilled peppers, whereas even 125 krad caused discoloration on the chilled ones. The radiation-induced softening, yellowing, and discoloration all impaired the quality of the peppers.

Globe Artichokes

Globe artichokes (*Cynara scolymus* L.) were irradiated with 0, 100, 200, 300, or 400 krad. Each sample consisted of 20 buds divided into subsamples of 5 buds each and packed in vented polyethylene bags. Following irradiation, samples were stored at 37° F. Separate samples were inspected for decay (Botrytis rot) and for overall appearance after 8 or 15 days in storage and after 3 additional days at 59°.

Three types of injury appeared on the artichokes: Stem pitting (dark sunken areas on the stems); external discoloration (brown scuffed-appearing areas on the outer bracts); and internal discoloration (reddish-brown spots on the inner bracts and blackening of the bases of the florets).

TABLE 13.—*Stem-scar mold, decay, and firmness of cantaloups as a function of radiation dose* [1]

Test No., quality criteria, and holding conditions	0 krad	45 krad	125 krad	250 krad	375 krad	500 krad
TEST 1 [2]						
Fruits with stem-scar mold:						
Held 7 or 10 days at 37° plus 3 days at 59° percent	38.3 a	46.4 a	40.9 a	—	9.8 b	—
Firmness (rating):[3]						
Held 7 or 10 days at 37°	3.4 a	3.1 ab	3.1 b	—	3.0 b	—
Held 7 or 10 days at 37° plus 3 days at 59°	2.9 a	2.7 a	3.0 a	—	2.8 a	—
TEST 2						
Fruits with decay (percent):[4]						
Held 8 days at 37° plus 4 days at 59°	0 a	—	5.0 a	0 a	13.0 a	45.0 b
Held 8 days at 37° plus 7 days at 59°	40.0 a	—	70.0 ab	90.0 b	93.0 b	98.0 b
Firmness (rating):[3 5]						
Held 8 days at 37°	4.4 a	—	4.3 a	4.1 ab	4.2 ab	3.8 b
Held 8 days at 37° plus 4 days at 59°	3.6 a	—	3.3 b	3.4 ab	3.2 b	2.9 c

[1] Any 2 means on a given line not followed by the same letter are significantly different from each other at the 1-percent level.

[2] The data are means for the 2 holding periods at 37° F.

[3] Rating scale: 1=unacceptably soft; 3=optimum softness for eating; 5=hard.

[4] No decay was present immediately after 8 days' storage at 37° F.

[5] Decay was too advanced after 7 days at 59° to rate cantaloups for firmness.

These injuries were rated on the following scale: 1=none; 2=trace; 3=slight; 4=moderate; 5=severe.

Radiation had no significant effect on Botrytis rot of the artichokes, but was the cause of the three types of injury (table 15). Severity of both stem pitting and internal discoloration increased with increasing radiation dose, but external discoloration was increased only by 300 and 400 krad. Both internal and external discolorations were more severe after 15 days at 37° than after 8 days, and the severity increased further with holding at 59° F. Stem pitting was equally severe at all examinations.

Lettuce and Endive

Head, leaf, and romaine lettuce (*Lactuca sativa* L. var. *capitata* L., *crispa* L., and *longifolia* Lam., respectively) and endive (*Cichorium endivia* L.) were irradiated with 0, 25, 50, 100, or 200 krad. Each sample of head lettuce consisted of 15 heads; the heads in half of the samples were wrapped with shrink film before irradiation. Samples of leaf and romaine lettuce and of endive consisted of eight unwrapped "heads" divided into subsamples of four heads each and packed in vented polyethylene bags. Following irradiation, all samples were held at 37° F. for 7 days before ex-

TABLE 14.—*Softening, yellowing, and calyx discoloration of bell peppers as a function of radiation dose and chilling exposure* [1]

Quality criteria and storage time and temperature	0 krad	125 krad	250 krad	375 krad	500 krad
Firmness (rating):[2]					
37° or 50° F.:					
Held 7 days	4. 2 a	3. 9 ab	4. 0 ab	3. 7 ab	3. 2 b
Held 12 days	3. 7 a	3. 6 ab	3. 2 ab	3. 1 ab	2. 8 b
Held 15 days	3. 3 a	3. 0 ab	2. 8 ab	2. 8 ab	2. 3 b
Color (rating):[3]					
37° F. (chilling):					
Held 7 days	1. 3 a	1. 6 b	1. 8 bc	1. 6 b	1. 8 c
Held 12 days	1. 4 a	1. 7 b	1. 7 b	1. 7 b	1. 6 ab
Held 15 days	1. 9 a	2. 1 a	2. 1 a	2. 0 a	2. 0 a
50° F. (nonchilling):					
Held 7 days	1. 3 a	1. 5 b	1. 9 c	1. 9 c	1. 9 c
Held 12 days	1. 8 a	1. 8 a	1. 9 a	2. 8 c	2. 4 b
Held 15 days	1. 8 a	1. 9 a	2. 4 b	2. 9 c	3. 3 d
Calyx discoloration (rating):[4]					
37° F. (chilling):					
Held 7 days	1. 0 a	1. 6 ab	2. 4 ab	2. 7 b	2. 6 b
Held 12 days	1. 0 a	2. 1 ab	3. 2 b	3. 1 b	2. 8 b
Held 15 days	1. 0 a	3. 1 b	3. 5 b	3. 8 b	3. 7 b
50° F. (nonchilling):					
Held 7 days	1. 0 a	1. 0 a	1. 0 a	1. 0 a	1. 8 a
Held 12 days	1. 1 a	1. 0 a	1. 1 a	1. 1 a	2. 7 b
Held 15 days	1. 0 a	1. 2 a	1. 0 a	2. 2 a	2. 4 a

[1] Any 2 means on a given line not followed by the same letter are significantly different from each other at the 1-percent level.
The data are means of examinations after the storage periods given and after 3 or 4 additional days at 59° F. combined.

[2] Rating scale: 1=unacceptably soft; 3=noticeably softened; 5=firm.

[3] Rating scale: 1=dark green; 3=yellow-green; 5=yellow.

[4] Rating scale: 1=none; 2=trace; 3=slight; 4=moderate; 5=severe.

TABLE 15.—*Decay and discoloration of globe artichokes as a function of radiation dose* [1]

Quality criteria		0 krad	100 krad	200 krad	300 krad	400 krad
Buds with decay	percent	70. 0 a	85. 0 a	81. 0 a	84. 0 a	83. 0 a
Stem pitting	rating [2]	1. 0 a	1. 9 b	3. 5 c	4. 5 d	4. 9 d
External discoloration	do.[2]	1. 3 a	1. 2 a	1. 3 a	2. 1 b	3. 7 c
Internal discoloration	do.[2]	1. 0 a	2. 5 b	3. 6 c	4. 8 d	5. 0 d

[1] Any 2 means on a given line not followed by the same letter are significantly different from each other at the 1-percent level. The data are the means of examinations after 8 or 15 days at 37° F. and after an additional 3 days at 59° combined.

[2] Rating scale: 1=none; 2=trace; 3=slight; 4=moderate; 5=severe.

amination. Separate samples were also examined after 3 additional days at 59°.

Three types of injury appeared on the lettuce: spotting (reddish-brown, often sunken spots on the leaves, especially along the midribs); brown heart (browning, especially along the leaf margins, of the young leaves in the center of the heads); and pink rib. Spotting was similar, but not identical, to the commonly observed russet spotting on lettuce. The severity of these disorders was rated on the following scale: 1=none; 2=trace; 3=slight; 4=moderate; and 5=severe.

Radiation reduced decay of head and leaf lettuce, but severely injured the leaves. Decay was nearly absent after holding at 37°. After the 3-day holding period at 59° F., most of the unirradiated head and leaf lettuce showed some decay, the incidence of which was significantly reduced by 50 krad on head lettuce and by 200 krad on leaf lettuce (table 16). Decay of endive was not significantly reduced by radiation, and no decay developed on the romaine lettuce. Following irradiation, all three types of lettuce as well as the endive developed spotting; all except head lettuce developed brown heart; and only head lettuce developed pink rib (table 17). The severity of these disorders increased with dose, and the injury was so great as to preclude irradiation of these crops. Injury was apparent at both examinations, although it became worse during holding at 59°. Wrapping of head lettuce in film did not influence the results.

TABLE 16.—*Decay of head lettuce, leaf lettuce, and endive as a function of radiation dose* [1]

Commodity	0 krad	25 krad	50 krad	100 krad	200 krad
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Head lettuce	73	80	40	0	3
Leaf lettuce	88	63	63	50	12
Endive	50	75	38	38	12

[1] Means on a given line underlined once are significantly different from 0 krad at the 1-percent level by chi-square analysis; means underlined twice are significantly different at the 0.1-percent level.

The data are based on the examination after holding 7 days at 37° F. plus 3 additional days at 59°. Decay was essentially absent after 7 days at 37° only.

Sweet Corn

Ten-ear samples of sweet corn (*Zea mays* L., var. *rugosa*) of the cultivar F-M Cross were irradiated with 0, 125, 250, or 500 krad. Ears were treated in the husk, or with husk removed, and were stored for 8 days at 32° F., during which time half of the samples were top-iced. The corn was examined immediately after storage and separate ears after 3 additional days at 41°. The only difference between irradiated and unirradiated corn was the amount of "denting" of the kernels, which was rated on the following scale: 1=none; 2=trace; 3=slight; 4=moderate; and 5=severe. Denting occurred as follows:

Radiation dose (krad)	0	125	250	500
Denting (rating)	2.1	2.1	2.4	3.0

The denting was worse on the husked than on the unhusked corn and was more severe at the second examination than at the first. The tabulation shows the means for both examinations. Sweet corn did not benefit from irradiation.

TABLE 17.—*Severity of spotting, brown heart, and pink rib of head, leaf, and romaine lettuce, and endive as a function of radiation dose* [1]

Quality criteria and commodity	0 krad	25 krad	50 krad	100 krad	200 krad
SPOTTING	*Rating*	*Rating*	*Rating*	*Rating*	*Rating*
Head lettuce	1.0 a	2.8 b	3.4 bc	4.5 cd	4.8 d
Leaf lettuce	1.0 a	3.4 b	3.5 bc	3.7 bc	3.9 c
Romaine lettuce	1.1 a	2.2 b	2.8 bc	2.9 bc	3.2 c
Endive	1.0 a	1.5 a	2.2 b	3.2 c	4.8 d
BROWN HEART					
Leaf lettuce	1.3 a	3.9 b	3.8 b	4.7 c	4.9 c
Romaine lettuce	1.0 a	1.5 b	2.3 c	3.0 d	3.7 e
Endive	1.3 a	1.7 a	3.1 b	3.9 c	4.9 d
PINK RIB					
Head lettuce	1.7 a	1.9 a	2.1 ab	2.2 ab	2.7 b

[1] Any 2 means on a given line not followed by the same letter are significantly different from each other at the 1-percent level. The data are the means for the examinations after 7 days at 37° and after 3 additional days at 59° combined.

Rating scale: 1=none, 2=trace, 3=slight, 4=moderate, 5=severe.

DISCUSSION

Theoretically, radiation is capable of extending the market life of vegetables by slowing physiological postharvest changes and decay. This expectation was fulfilled with mushrooms, for which the market life was extended by several days, and partly for sweetpotatoes, for which sprouting was inhibited during extended storage. While sprouting during storage and marketing is usually not a serious problem with sweetpotatoes, under some conditions sprouting does occur and its prevention by irradiation might be desirable. No consistent pattern of decay control was observed for the various crops tested. Irradiation of tomatoes sometimes reduced, sometimes increased, and sometimes had no effect on decay. Stem-scar mold of cucumbers and cantaloups was reduced in one test each, but in subsequent tests, decay of cucumbers was unaffected and decay of cantaloups was greatly increased by radiation. Radiation increased susceptibility of sweetpotatoes to decay during storage.

Quality of the vegetables was impaired in several ways by radiation. Undesirable softening of tomatoes, cucumbers, cantaloups, and peppers was associated with irradiation, especially with the higher doses, and was often accompanied by objectionable color changes. The blotchy ripening or mottling of irradiated tomatoes greatly detracted from their appearance, and the radiation-induced yellowing of cucumbers, peppers, and scallop squash made them look older and less appealing than the controls. Denting of sweet corn, which is associated with aging, was accelerated by radiation. The discoloration and spotting of artichokes, lettuce, and endive after irradiation completely destroyed their market value.

The responses of vegetables to radiation were not greatly influenced by the experimental variables that were tested. Differences in response to irradiation among varieties were not apparent with tomatoes, summer squash, and lettuce, but there were distinct differences among the three varieties of sweetpotatoes. The degree of ripeness at the time of irradiation influenced responses of tomatoes, but the differences in response occurred over a broad range of ripeness classes. Storage temperature was an important variable: radiation apparently increased the sensitivity of susceptible vegetables to chilling injury; irradiated sweetpotatoes, tomatoes, and peppers were injured more than the controls when held at chilling temperatures. It is clear, therefore, that considerable care would have to be taken to avoid storing irradiated chilling-sensitive vegetables at chilling temperatures, should irradiation ever be used commercially on these crops.

In these tests, radiation was an effective growth inhibitor, but it was not an effective decay-control agent on fresh vegetables. Decay reduction was variable; when some reduction was effected, it was usually accompanied by injury that reduced the market value of the vegetables. This conclusion diverges sharply from earlier optimistic appraisals of the benefits of irradiation (*6*), but those opinions were based largely on results with processed or partly processed produce. The sensitivity of the living host to radiation severely restricts the use of radiation on fresh vegetables.

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APPENDIX

Table 18.—*Sweetpotatoes: Statistical significance of the effects of radiation, variety, storage temperature, storage time, holding time at 70° F., and certain interactions* [1]

Quality criteria	Radiation (R)	Variety (V)	Storage temperature (T)	Storage time (S)	Holding time (H)	R×V	R×T	R×S	R×H
Decay	(**)	(**)	(**)	(**)	(**)	(*)	(**)	n.s.	n.s.
Weight loss	(**)	(*)	(**)	(**)	n.s.	n.s.	(**)	(**)	n.s.
Sprouting	(**)	(*)	(**)	(**)	n.s.	n.s.	(**)	n.s.	n.s.

[1] The level of statistical significance is denoted as follows:
n.s.=no significance.
*=significance at the 5-percent level.
**=significance at the 1-percent level.

This table applies only to the Porto Rico and Yellow Jersey varieties. Variety No. 23 is not included because it was obtained from only one grower.

Table 19.—*Tomatoes: Statistical significance of the effects of radiation, initial ripeness, chilling, ripening time, and certain interactions* [1]

Quality criteria and test No.[2]	Radiation (R)	Initial ripeness (I)	Chilling (C)	Ripening time (T)	R×I	R×C	R×T	I×C	I×T	C×T
DECAY										
1	(**)	(**)	(**)	(**)	(**)	(*)	n.s.	(**)	n.s.	(*)
2	(**)	n.s.	(**)	(**)	n.s.	(*)	n.s.	(**)	n.s.	(**)
3	(**)	n.s.	--------	(**)	n.s.	--------	n.s.	--------	(**)	--------
4 F	n.s.	n.s.	--------	n.s.	n.s.	--------	n.s.	--------	n.s.	--------
N.Y.	(**)	n.s.	--------	(**)	n.s.	--------	n.s.	--------	(**)	--------
SOFTENING										
1	(**)	n.s.	(**)	(**)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
2	(**)	(**)	(**)	(**)	n.s.	n.s.	n.s.	(**)	(**)	n.s.
3	(**)	(**)	--------	(**)	(**)	--------	(*)	--------	(**)	--------
4 F	(*)	(**)	--------	(**)	n.s.	--------	n.s.	--------	n.s.	--------
N.Y.	(**)	n.s.	--------	(**)	n.s.	--------	n.s.	--------	n.s.	--------
COLOR										
1	(**)	(**)	n.s.	(**)	(**)	n.s.	n.s.	n.s.	(**)	n.s.
2	(**)	(**)	(**)	(**)	(*)	n.s.	(*)	(**)	(**)	n.s.
3	(**)	n.s.	--------	(**)	(*)	--------	(**)	--------	(*)	--------
4 F	(*)	(*)	--------	(*)	n.s.	--------	n.s.	--------	n.s.	--------
N.Y.	n.s.	(**)	--------	(*)	n.s.	--------	n.s.	--------	(**)	--------
MOTTLING										
1	(**)	(**)	(**)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
2	(**)	n.s.	(**)	(**)	n.s.	(**)	(**)	n.s.	n.s.	n.s.
3	(**)	(**)	--------	n.s.	(**)	--------	n.s.	--------	(**)	--------
4 F	n.s.	n.s.	--------	n.s.	n.s.	--------	n.s.	--------	n.s.	--------
N.Y.	(**)	(**)	--------	n.s.	n.s.	--------	n.s.	--------	(*)	--------

[1] The level of statistical significance is denoted as follows:
n.s.=no significance.
*=significance at the 5-percent level.
**=significance at the 1-percent level.

[2] F.=lots held at Fresno; N.Y.=lots shipped to New York.

TABLE 20.—*Cucumbers: Statistical significance of the effects of radiation, chilling, holding time at 59° F., and certain interactions* [1]

Test No. and quality criteria	Radiation (R)	Chilling (C)	Holding time (T)	R×C	R×T
TEST 1					
Stem-scar mold	(**)	n.s.	(*)	n.s.	n.s.
Yellowing	n.s.	(**)	(*)	n.s.	n.s.
Softening	(**)	(**)	n.s.	n.s.	n.s.
Shriveling	n.s.	n.s.	n.s.	(**)	n.s.
TEST 2					
Decay	n.s.	(**)	(**)	n.s.	n.s.
Weight loss	n.s.	(**)	(**)	n.s.	n.s.
Yellowing	(**)	(**)	(**)	n.s.	n.s.
Softening	(**)	(**)	(**)	n.s.	n.s.

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[1] The level of statistical significance is denoted as follows:
n.s.=no significance.
*=significance at the 5-percent level.
**=significance at the 1-percent level.

TABLE 21.—*Summer squash: Statistical significance of the effects of radiation, variety, chilling, holding time at 55° F., and certain interactions* [1]

Criteria	Radiation (R)	Variety (V)	Chilling (C)	Holding time (T)	R×V	R×C	R×T
Decay	(*)	(*)	(**)	n.s.	n.s.	n.s.	n.s.
Weight loss	n.s.	(**)	(*)	(**)	n.s.	n.s.	n.s.
Softening	(**)	(*)	(**)	(**)	n.s.	n.s.	n.s.

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[1] The level of statistical significance is denoted as follows:
n.s.=no significance.
* =significance at the 5-percent level.
** =significance at the 1-percent level.

TABLE 22.—*Cantaloups: Statistical significance of the effects of radiation, initial ripeness, storage time, and certain interactions*[1]

Test No., quality criteria, and holding conditions	Radiation (R)	Initial ripeness (I)	Storage time (S)	R×I	R×S
TEST 1					
Stem-scar mold:					
Held 7 or 10 days at 37° plus 3 days at 59° F	(**)	n.s.	(**)	n.s.	n.s.
Firmness:					
Held 7 or 10 days at 37°	(*)	(**)	n.s.	n.s.	n.s.
Held 7 or 10 days at 37° plus 3 days at 59°	n.s.	(**)	n.s.	n.s.	n.s.
Ground color:					
Held 7 or 10 days at 37°	n.s.	(**)	n.s.	n.s.	n.s.
Held 7 or 10 days at 37° plus 3 days at 59°	n.s.	(**)	n.s.	n.s.	n.s.
TEST 2					
Stem-scar mold:					
Held 8 days at 37° plus 4 days at 59°	n.s.	(**)	----------	n.s.	----------
Held 8 days at 37° plus 7 days at 59°	n.s.	n.s.	----------	n.s.	----------
Decay:					
Held 8 days at 37° plus 4 days at 59°	(**)	(*)	----------	(*)	----------
Held 8 days at 37° plus 7 days at 59°	(**)	n.s.	----------	n.s.	----------
Firmness:					
Held 8 days at 37°	(*)	(**)	----------	n.s.	----------
Held 8 days at 37° plus 4 days at 59°	(**)	(**)	----------	n.s.	----------
Ground color:					
Held 8 days at 37°	n.s.	(**)	----------	n.s.	----------
Held 8 days at 37° plus 4 days at 59°	(*)	(**)	----------	(*)	----------

[1] Statistical significance is denoted as follows:
n.s.=no significance.
*=significance at the 5-percent level.
**=significance at the 1-percent level.

TABLE 23.—*Bell peppers: Statistical significance of the effects of radiation, chilling, holding time at 37° or 50° F., and certain interactions*[1]

Quality criteria	Radiation (R)	Chilling (C)	Holding time (T)	R×C	R×T
Decay	n.s.	n.s.	(*)	n.s.	n.s.
Firmness	(**)	n.s.	(**)	n.s.	n.s.
Color	(**)	(**)	(**)	(**)	n.s.
Calyx discoloration	(**)	(**)	(**)	(**)	n.s.

[1] The level of statistical significance is denoted as follows:
n.s.=no significance.
*=significance at the 5-percent level.
**=significance at the 1-percent level.

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